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ORIGINAL RESEARCH

RAPID KNEE-EXTENSIONS TO INCREASE QUADRICEPS MUSCLE ACTIVITY IN PATIENTS WITH TOTAL KNEE ARTHROPLASTY: A RANDOMIZED CROSS-OVER STUDY

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ABSTRACT

Background: Inhibition of the quadriceps muscle and reduced knee-extension strength is common shortly following total knee arthroplasty (weeks to months), due to reduced voluntary activation of the quadriceps muscle. In healthy subjects, strength training with heavy loads is known to increase agonist muscle activity, especially if the exercise is conducted using rapid muscle contractions.

Purpose: The purpose of this study was to examine if patients with total knee arthroplasty could perform rapid knee-extensions using a 10 RM load four to eight weeks after surgery, and the degree to which rapid knee-extensions were associated with greater voluntary quadriceps muscle activity during an experimental strength training session, compared to that elicited using slow knee-extensions.

Study Design: A randomized cross-over study.

Methods: Twenty-four patients (age 66.5) 4-8 weeks post total knee arthroplasty randomly performed one set of five rapid, and one set of five slow knee-extensions with the operated leg, using a load of their 10 repetition maximum, while surface electromyography recordings were obtained from the vastus medialis and lateralis of the quadriceps muscle.

Results: Data from 23 of the 24 included patients were analyzed. Muscle activity was significantly higher during rapid knee-extensions (120.2% [10^{th}-90^{th} percentile: 98.3-149.1]) compared to slow knee-extensions (106.0% [88.8-140.8]) for the vastus lateralis ($p < 0.01$), but not for the vastus medialis (120.8% [90.4-134.0]) and (121.8% [93.0-133.0]) ($p = 0.17$), respectively. Slow and rapid knee-extensions were performed at a median angular velocity of 19.7 degrees/sec (13.7-24.4) and 51.4 degrees/sec (28.9-63.1), respectively

Conclusion: Four to eight weeks after their total knee arthroplasty, the patients in the present study were able to conduct rapid knee-extensions according to the experimental protocol with an approximately doubled angular velocity compared to slow knee-extensions. This was associated with increased muscle activity in the vastus lateralis when compared to slow knee-extensions, but not in the vastus medialis. Whether this significant, although relatively small, difference in vastus lateralis muscle activity has any clinical relevance needs further study.

Level of Evidence: 3

Keywords: Exercise evaluation, knee-extension velocity, quadriceps muscle, rehabilitation, total knee arthroplasty

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BACKGROUND

Total knee arthroplasty (TKA) is a recommended intervention for end-stage knee joint osteoarthritis (OA),[1] and in many cases it successfully relieves pain and discomfort.[2,3] Although current perioperative care is dominated by fast track or enhanced recovery programs, which have successfully reduced length of hospital stays,[4,5] a substantial reduction in knee-extension strength and rate of torque development is still a major pathophysiological problem weeks to months following surgery.[6,7] Adding to this problem is the fact that knee-extension strength is reduced already before surgery [2,8] but is exacerbated further post-surgery,[2,9–11] with an average reduction of 83 % at hospital discharge compared to pre-surgery values.[12] The loss of knee-extension strength is not always resolved over time, as a large body of evidence indicates persistent knee-extension strength weakness months [2,10,13–15] and years [7,14,16] after surgery, compared to the non-affected contralateral limb or limbs of age-matched healthy peers.

The acute loss of knee-extension strength following TKA is caused primarily by reduced voluntary activation of the quadriceps muscle, known as arthrogenic muscle inhibition (AMI).[9,17-18] The cause of AMI is multifactorial, but some of the key mechanisms are thought to be inflammation, swelling, and receptor damage following surgery.[17] Because of this, afferent signaling from the knee joint is altered post-surgery, affecting the central nervous system (CNS) by changing the excitability of multiple spinal and supraspinal pathways, which inhibits the quadriceps muscle and reduces knee-extension strength.[17,18] In patients with TKA, this results in limited force production for the execution of tasks of everyday living,[19,20] e.g. reduced gait speed, walking distance and stair climbing ability [2,13,21] as well as increased risk of falls.[22]

The latest systematic review and consensus recommendation on rehabilitation following TKA does not find evidence for a specific type of exercise program, but progressive strength training of the lower limbs is one of the exercise modalities recommended.[23,24] When healthy subjects perform strength training using heavier loads, it is generally associated with pronounced neural adaptations, such as increased voluntary activation of the trained muscle [25,26] especially if the exercise is executed using rapid contractions.[27,28] In patients following total hip arthroplasty, progressive explosive resistance training has been associated with increased maximal strength and rate of force development in the quadriceps muscle after 12 weeks of progressive resistance training.[29] Similarly, recent preliminary results showed significantly greater improvements in walking distance and knee-extension strength after eight weeks of high velocity knee-extension exercise (concentric phase < 1 second, eccentric phase 3 seconds) compared to slow velocity knee-extension exercise (concentric and eccentric phases each 3 seconds) performed four to six weeks after surgery in patients with TKA.[30] In healthy individuals, greater activity in the quadriceps muscle has also been shown as an acute effect to a single set of rapid knee-extensions compared to slow knee-extensions.[31,32] Accordingly, if rapid knee-extensions can be performed during strength training shortly following TKA, this may be a simple way to reduce AMI after surgery with the intention of better and faster recovery. Previous studies investigating rapid versus slow contractions in patients shortly following TKA report how they used verbal directions and metronomes to help guide the movement velocity, however they did not measure the degree to which the angular velocity was actually different between the rapid and slow contractions.[30,33]

The purpose of this study was to examine if patients with total knee arthroplasty could perform rapid knee-extensions using a 10 RM load four to eight weeks after surgery, and the degree to which rapid knee-extensions were associated with greater voluntary quadriceps muscle activity during an experimental strength training session, compared to that elicited using slow knee-extensions. The authors hypothesized that the rapid knee-extensions would increase quadriceps muscle activity more than the slow knee-extensions.

METHODS

Study design

The protocol consisted of a familiarization session where the 10 RM load for knee-extension (the maximum number of repetitions per set that can be performed at a given resistance with proper lifting technique) [34] was determined, and a subsequent experimental session at least three days later where surface electromyography (EMG) recordings of the quadriceps muscle were made during slow and rapid knee-extensions. For the experimental session, a randomized cross-over design was used, with a balanced randomization (1:1, slow and rapid knee-extensions, respectively). That is, 12 patients started with the slow contractions and completed the rapid afterwards, and the other 12 patients started with the rapid contractions and completed the slow afterwards. Further, the data analyst was blinded with respect to contraction type.

The present study was embedded in a study evaluating knee-extension muscle activity across different exercises after TKA (unpublished, ClinicalTrials.gov identifier: NCT01708980). All outcomes for this

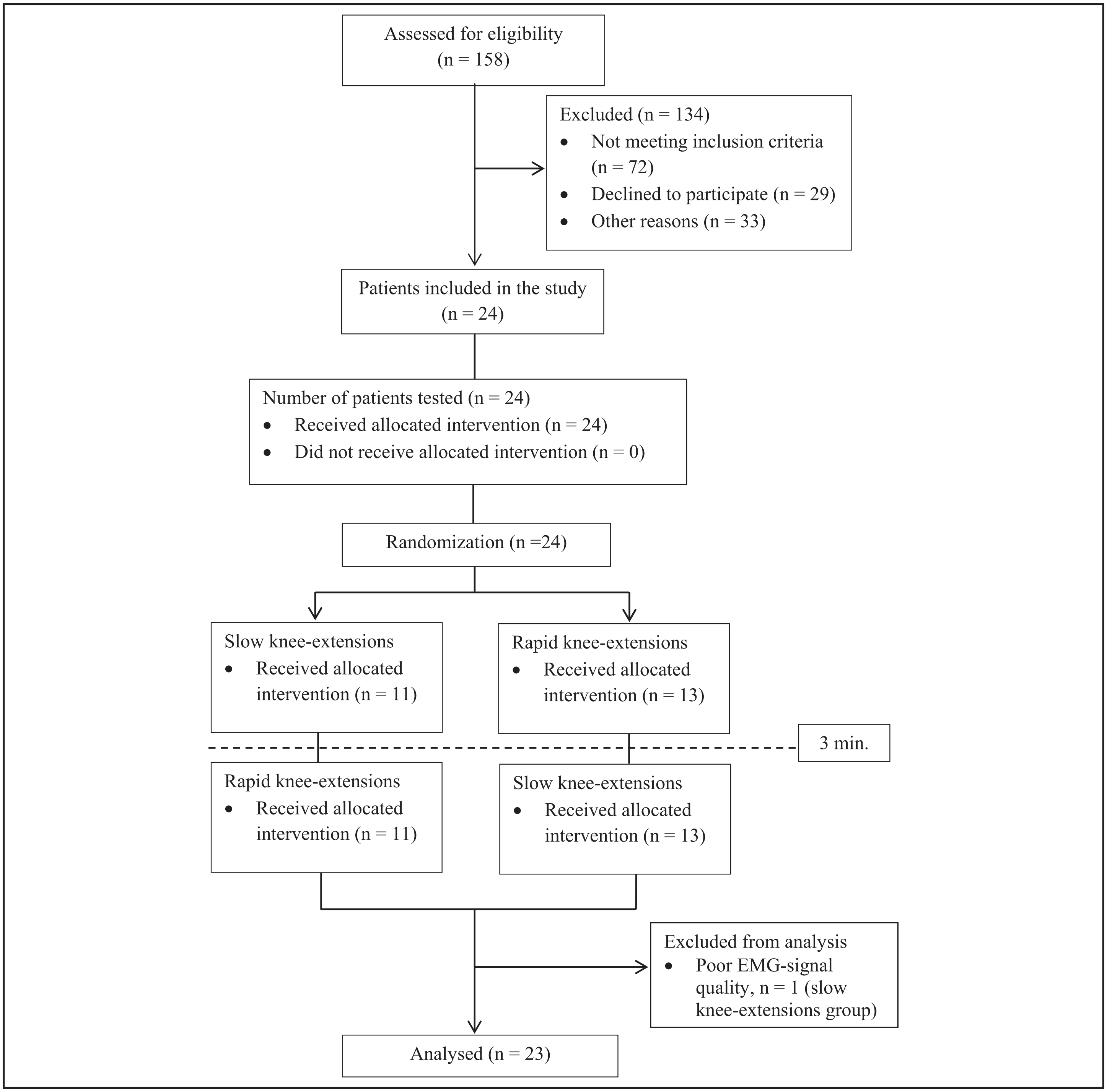

Figure 1. *Flow chart of participating patients and study design.*

embedded study were pre-defined and the analyses were made blinded.

The reporting of the study follows CONSORT 2010 Explanation and Elaboration: updated guidelines for reporting parallel group randomized trials [35] and Standards for Reporting EMG Data suggested by Merletti.[35] The protocol for this trial was approved by The Committee on Biomedical Research Ethics for the Capital Region of Denmark (H-1-2011-027).

Participants

Twenty-four patients were recruited during their out-patient rehabilitation by consecutive sampling from four different rehabilitation centers in the Copenhagen Area (Vanløse, Vesterbro/Kgs. Enghave/Valby, Brøndby and Hvidovre). The inclusion criteria were: patients having received TKA surgery four to eight weeks prior to testing, and were 18-80 years of age. The exclusion criteria were: less than 70 degrees of active range of motion flexion in the operated knee, if they had alcohol or substance abuse or if they had any other musculoskeletal or neurological disorder requiring specialized rehabilitation. Prior to the study, all patients were informed about the study, both verbally and in writing as defined in The Declaration of Helsinki. All patients gave their written informed consent to participation in the study.

Intervention

At the familiarization session, all individual preparations and adjustments were made, and at the experimental session a strength training session was simulated, at which the experiments were conducted.

Familiarization session: At the familiarization session, the knee-extension strength training machine (TechnoGym, Silverline, Rehabilitation Device, Bracknell, United Kingdom) was individually adjusted to each patient for the testing of both maximal voluntary isometric contraction (MVC) in knee-extension at a knee joint angle of 60 degrees and dynamic knee-extensions, during which the patients should be able to employ a minimum range of 70 degrees (10 to 80 degrees of knee-flexion). The adjustments placed each patient in 90 degrees bilateral hip-flexion and with the resistance pad of the machine placed on the front of the lower part of the shin bone, approximately 5 cm above the lateral malleolus (Figure 2).

Figure 2. *Experimental arrangement: Patients seated in a knee-extension machine with a resistance pad against the lower shin bone and with the back against a backrest.*

Each patient then performed a three minute warm up on a stepping machine at a self-selected, but submaximal intensity. The warm up was followed by sets of slow dynamic knee-extensions to determine the load in kilograms corresponding to 10 RM, and was supervised by an experienced physical therapist. This was typically accomplished in one to three attempts, according to the physical therapist's best estimate.

To standardize knee-extension velocity, the patients were guided by an audio file. Instructions on how to perform the knee-extensions in a smooth manner in the required range of joint motion without pauses or resting the weight stacks in between knee-extensions were given. Before ending the familiarization session, patients practised both slow and rapid knee-extensions, and were then randomized to the order of knee-extensions for the subsequent experimental session.

Experimental session: Subsequently to a warm up as for the familiarization session, the patients performed three knee-extension MVC's, separated by two-minute pauses, for the operated knee with the knee joint positioned at 60 degrees flexion. Instructions were given to extend the knee as strongly as possible against the fixed resistance pad of the knee-extension machine for approximately five seconds, thereby gradually building up force to a maximum. To facilitate patients in achieving their maximum force, standardized and vigorous verbal encouragement was provided. The highest EMG value obtained from the three MVC's where used as reference for the subsequent EMG amplitude normalization.

The patients then performed a single set of five rapid and a single set of five slow dynamic knee-extensions with the operated leg using a load of 10 RM according to the randomization order. The five repetitions at 10 RM were used to avoid fatigue during the knee-extensions. The pre-recorded audio files assisted the patients in managing the velocity-specific timing during both slow and rapid knee-extensions. Slow knee-extensions were performed in a 10-second loop audio file, with three, two and three seconds for the concentric, isometric and eccentric phases, respectively, and a two-second pause in resting knee-flexion between the repetitions, aiming for an angular velocity of 20 degrees/sec. Rapid knee-extensions were performed in an eight-second cycle, consisting of approximately one second (or less if possible for the patient – aiming for an angular velocity ≥ 60 degrees/sec) to perform the concentric contraction phase on the command "*LIFT*", two seconds for the isometric hold in extension, followed by three seconds of eccentric contraction and two seconds of pause in knee-flexion. The concentric contractions, performed on the command "*LIFT*", were executed with an intention to attain maximal acceleration and velocity; thereby knee-extension velocity during the rapid knee-extensions could potentially be, three times faster than the slow knee-extensions. Consequently, the achieved angular velocity was dependent on each patient's ability to perform knee-extensions rapidly.

Muscle activity during the knee-extensions was recorded using an EMG system from Delsys (Bagnoli EMG™ System, Delsys, Natick, Massachusetts). At the start of the experimental session, standard skin and electrode preparation, consisting of careful shaving, abrasion and cleaning of the skin, as well as application of gel and medical-grade adhesive to the electrodes, was carried out. Non-disposable rectangular single-differential surface electrodes (DE 2.1, Delsys, Natick, Massachusetts), with a length and an interpole-distance of 1 cm, were placed on the skin overlying the vastus medialis (four finger-breadths proximal to the superior-medial angle of the patella) and lateralis (over the lateral aspect of the thigh, one handbreadth above the patella), of the quadriceps muscle, as described by Perotto and associates.[36] A reference electrode was placed over the patella bone. To avoid movement artefacts, all wires were taped carefully to the skin.

The EMG signals were sampled at 1000 Hz (16-bit A/D converter, 6036E, National Instruments, Hørsholm, Denmark), amplified at the electrode level via built-in preamplifiers, and transmitted through insulated wires to a main amplifier unit (Bagnoli-16, Delsys, Natick, Massachusetts) that filtered the signals using a bandwidth of 20 to 450 Hz, with a common-mode rejection ratio of 92dB. Prior to data collection, EMG signal quality was assessed visually during light contractions of the quadriceps muscle. An electrical goniometer (Goniometer Biosignal Sensors, Delsys, Natick, Massachusetts) was mounted with adhesive tape on the lateral side of the knee to quantify the knee joint range of motion (Figure 3).[37]

Outcomes

Primary outcome: During the offline EMG analysis (EMGworks 3.7 Analysis, Delsys, Natick, Massachusetts), the EMG amplitudes recorded during the slow and rapid concentric contractions (knee-extension) were normalized to the peak EMG amplitude (EMGmax) determined from the MVCs, and expressed as percentage of this value (%EMGmax). For both slow and rapid contractions, muscle activity was calculated as a mean of the peak amplitudes for each of the five knee-extensions. A smoothing root mean square (RMS) filter was initially applied to the raw data. For the MVCs, the RMS values were calculated using a 1-second window length and a 0.999-second window overlap. The MVC with the greatest amplitude was used as the EMGmax data point for each muscle. For the rapid and slow knee-extensions, the concentric phase was initially located using the goniometer recordings (Figure 3). The RMS values were then calculated for the concentric phases using a 0.200-second window length and 0.199-second window overlap.

Secondary outcomes: The secondary outcomes were knee-extension velocity at slow and rapid knee extensions, and pain in the operated knee at rest, during and after knee-extensions. Knee-extension

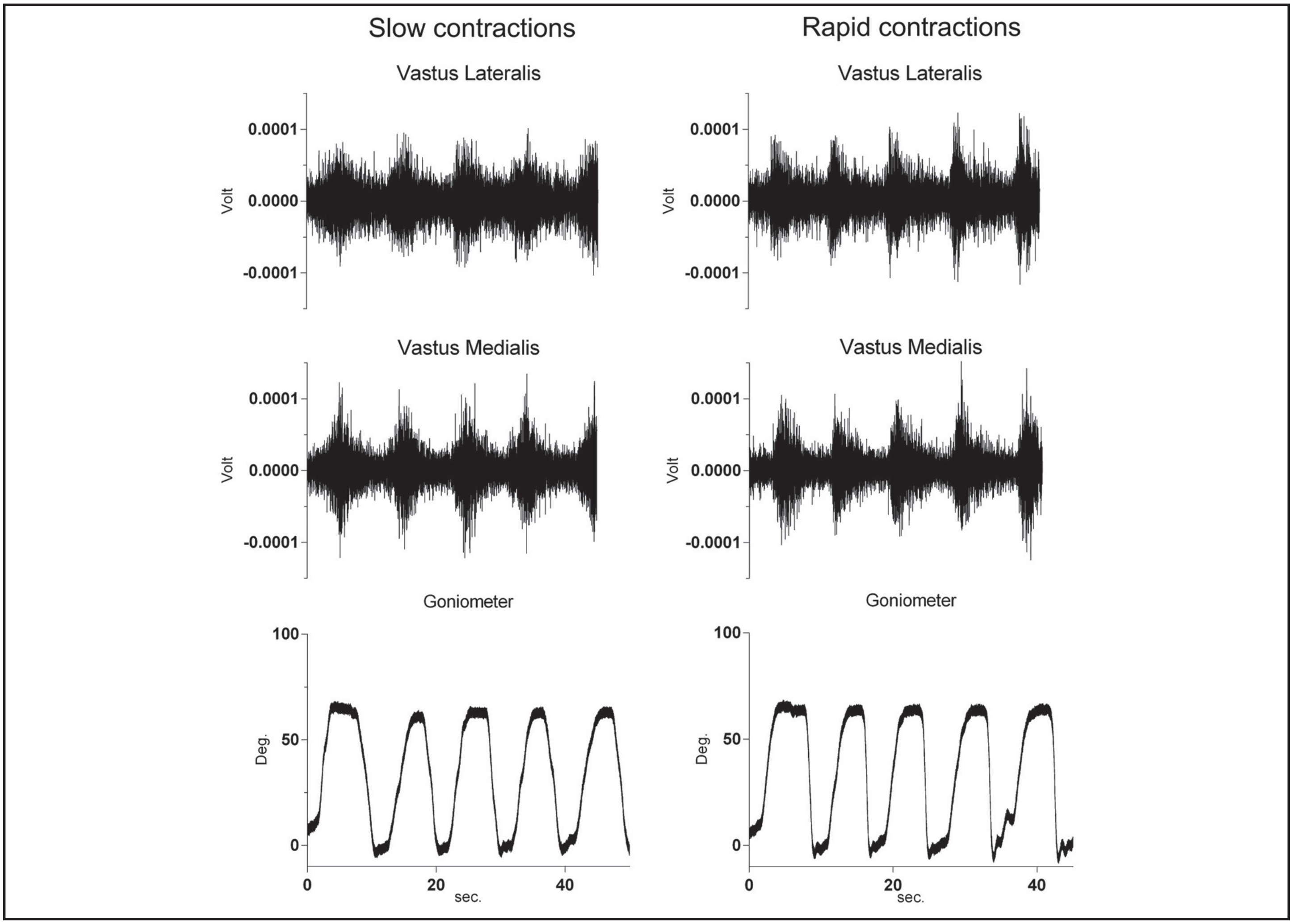

Figure 3. *Raw EMG and goniometer traces. Top and middle rows show raw EMG traces of 5 slow (left) and 5 rapid (right) knee-extensions, measured in vastus lateralis (top) and vastus medialis (middle) of the quadriceps muscle. Lower row shows the corresponding goniometer trace as a patient performs 5 slow (left) and 5 rapid (right) knee-extensions.*

velocity during slow and rapid knee-extensions was measured with the electrical goniometer mounted on the lateral side of the knee (Figure 3). This measurement was used to validate the experimental protocol, that is, that the rapid contractions were in fact more rapid than the slow contractions. Pain was assessed using a 100-mm visual analogue scale (VAS) with endpoints of 0 representing "no pain" and 100 representing "worst pain imaginable". Patients were asked to rate their pain in the operated knee at rest in real time and during the following activities by recall: Ten RM load determination (familiarization session), MVC and, rapid and slow contractions (experimental session). Pain at rest was measured immediately before and approximately one minute after every type of activity. Pain during activity was measured within seconds after completion of the knee-extensions by recall.

Randomization and blinding

Concealed envelopes were used to randomly allocate all patients to the order of knee-extension velocity. It was not possible to blind either patients or the investigators to the velocity of the test, but the data analyst was blinded. Furthermore, the patients were blinded with regard to the study hypothesis.

Statistical analyses

A power analysis was initially performed using a significance level of 5% (two-tailed t-test), a power of 80%, a mean muscle activity of 85 %EMGmax, and a common standard deviation of 18 %EMGmax,[38] which showed that 23 subjects were needed to show a 15% difference in quadriceps muscle activity between knee-extensions types (15% more muscle activity during rapid compared to slow knee-extensions). We considered the 15% difference in muscle activity the minimal clinical important difference. To account for potential dropout or missing data, 24 patients were included.

The statistical analyses were performed using STATA (version STATA13.1). By the use of histograms, scatterplots, Shapiro Wilk tests and Q-Q-plots of the residuals, it was observed that data were skewed and non-normally distributed. Consequently, it was decided to use non-parametric statistics and to present data as medians with corresponding 10^{th}-90^{th} percentile ranges.

Between knee-extension-velocity differences in muscle activity and activity-related knee pain differences during both rapid and slow knee-extensions, as well as resting knee pain differences before and after both rapid and slow knee-extensions, were assessed using Wilcoxon sign rank tests.

RESULTS

Patients

A total of 158 potentially eligible patients with TKA referred to the four rehabilitation centers were assessed for eligibility, and 24 patients were included (days after surgery, mean (SD) 38.3 [9.4]) (Figure 1). Data from one patient was subsequently discarded during the offline EMG analysis due to poor signal quality, thus, data from 23 patients were analysed. The decision to discard data from this patient was made prior to the data analysis. Two of the 23 patients only completed three rapid knee-extensions and one patient only completed four rapid knee-extensions. A fourth patient only completed four repetitions of the slow knee-extensions. These four patients that did not complete the intended number of repetitions were analysed using the available data. Patient characteristics of the 23 patients are presented in Table 1.

Outcomes

Primary outcome: Muscle activity was significantly higher during rapid knee-extensions (120.2 %EMGmax [98.3-149.1]) (values expressed as median and 10^{th}-90^{th} percentile ranges) compared to slow knee-extensions (106.0 %EMGmax [88.8-140.8]) for the vastus lateralis ($p < 0.01$). Muscle activity was not significantly higher during rapid knee-extensions (120.8 %EMGmax (90.4-134.0)) compared to slow knee-extensions (121.8 %EMGmax [93.0-133.0) for the vastus medialis ($p = 0.17$) (Table 2).

Secondary outcomes: Slow knee-extensions were performed at standardized velocities at a median angular velocity of 19.7 degrees/sec (13.7-24.4) and

Table 1. *Baseline characteristics for patients*

Variable	Slow knee-extensions first (n = 10)	Rapid knee-extensions first (n = 13)
Male	n = 6 (26.1 %)	n = 4 (17.4 %)
Female	n = 4 (17.4 %)	n = 9 (39.1 %)
	Median (10^{th}-90^{th})	**Median (10^{th}-90^{th})**
Age (years)	68 (57-78)	65 (58-77)
Height (cm)	178 (167-190)	168 (158-182)
Body mass (kg)	83 (73-103)	86 (69-111)
VAS (0-100 mm)	0 (0-11)	0 (0-7)

Baseline data on patients randomized into 2 groups defined by order of contraction type. Gender distribution is reported as absolute numbers in each group and the relative number in percentage. All other variables are presented as median (10_{th}-90_{th} percentile).
VAS = Visual Analogue Scale.

Table 2. *Primary and secondary outcomes. The primary outcome is normalized EMG amplitudes (%EMGmax) and the secondary outcomes are angular velocity (degrees/sec) and pain measurement before, during and after testing procedures. All data are reported as median (10th-90th percentile)*

Primary outcome	**Slow knee-extensions**	**Rapid knee-extensions**
Vastus medialis muscle activity, %EMGmax	121.8 (87.8-141.0)	120.8 (87.4-155.1)
Vastus lateralis muscle activity, %EMGmax	106.0 (88.8-140.8)	120.2 (98.3-149.1)*
Secondary outcomes	**Slow knee-extensions**	**Rapid knee-extensions**
Angular velocity, deg/sec	19.7 (13.7 -24.4)	51.4 (28.9-63.1)*
Resting pain pre knee-extensions, VAS (0-100 mm)	0 (0-2)	0 (0-2)
Resting pain post knee-extensions, VAS (0-100 mm)	0 (0-2)	0 (0-5)*
Activity pain during knee-extensions, VAS (0-100 mm)	0 (0-39)¤	0 (0-51)¤
Secondary outcomes	**10 RM load determination**	**MVC**
Resting pain pre knee-extensions, VAS (0-100 mm)	0 (0-14)	0 (0-9)
Resting pain post knee-extensions, VAS (0-100 mm)	0 (0-0)	0 (0-2)
Activity pain during knee-extensions, VAS (0-100 mm)	16 (0-48)¤	0 (0-42)¤

*Denotes significant difference between slow and rapid knee-extensions, $p<0.05$. ¤ Denotes significant difference between activity pain level and resting pain level, $p<0.05$. VAS = Visual Analogue Scale, RM = Repetition Maximum. MVC = Maximum Voluntary Contraction.

rapid knee-extensions at 51.4 degrees/sec (28.9-63.1), which were significantly different ($p < 0.01$).

Activity-related knee pain during the rapid knee-extensions (VAS = 0 mm [0-51]) was not significantly higher ($p = 0.36$), compared to that during the slow knee-extensions (VAS = 0 mm [0-39]). Resting knee pain after rapid knee-extensions (VAS = 0 mm [0-5]) was significantly higher ($p = 0.0046$) compared to resting knee pain after slow knee-extensions (VAS = 0 mm [0-2]). For both the 10 RM load determination and the MVC's there was no significant difference between resting pain levels before or following the two activities ($p > 0.05$). The activity-related pain was significantly higher for both the 10 RM load determination (VAS = 16 mm [0-48]) and the MVC's (VAS = 0 mm [0-42]) compared to resting pain levels, VAS = 0 mm (0-14) and 0 mm (0-9), respectively ($p < 0.05$) (Table 2).

No adverse events were experienced by the patients.

DISCUSSION

In general, patients, four to eight weeks post TKA surgery, were able to more than double their knee-extension velocity during the rapid knee-extensions compared to slow. In doing so, the primary hypothesis was partly confirmed, as rapid knee-extensions, compared to slow knee-extensions, increased muscle activity significantly in the vastus lateralis muscle, but not in the vastus medialis muscle. Although the difference was significant in vastus lateralis it was relatively small and whether this has any clinical relevance needs further study. Secondly, the patients with TKA did not experience a higher increase in knee pain during the rapid knee-extensions compared to slow knee-extensions.

Results from two recent studies add to the equivocal interpretation of the findings in the present study.[30,33] Doerfler and colleagues found that an eight-week high-velocity exercise program commenced four to six weeks after TKA increased knee-extension strength more than a slow velocity exercise program.[30] These results, at least in part, are consistent with the results of the present study suggesting a (clinically relevant) effect of exercise comprising high knee-extension velocity. To the contrary, Kelly and colleagues did not find a difference between groups performing high velocity exercise compared to slow velocity exercise for seven weeks on e.g. the stair climb test in patients with TKA commenced 10-21 days after surgery.[33]

Interpretation

Feasibility of rapid knee-extensions as training modality: For the patients in this study, the increase in activity-related knee pain during rapid knee-extensions was not significantly higher than during slow knee-extensions (Table 2). However, a significant, albeit not clinically relevant (<10% difference),[40] increase was registered in pain after rapid knee-extensions compared to slow knee-extensions. Thus, in spite of this statistical difference in pain after rapid and slow knee-extensions, this training modality appears feasible for patients four to eight weeks post TKA.

Muscle activity in vastus lateralis: The observed median increase in muscle activity in vastus lateralis of 8.5 % EMGmax during the rapid knee-extensions is indicative of additional motor unit recruitment and/or increased motor unit discharge rate, caused by increased CNS activation in order to increase knee-extension velocity.[41] In the literature, there is no clear consensus on the precise relationship between different velocities and coexisting EMG amplitudes, as these are also influenced by other factors such as external load and joint angle.[39,42]

Croce et al, investigated the effect of submaximal contraction intensity and velocity on EMG amplitude in the quadriceps muscle during knee-extensions, and observed the lowest EMG amplitudes at 50 degrees/sec when comparing to higher velocities.[42] Thus, it is possible that the patients in the present study were unable to perform maximal velocity knee-extensions sufficiently fast to promote EMG amplitudes that were markedly higher than those elicited at slow velocity. Consequently, it is possible that a more pronounced difference in muscle activity (i.e. EMG amplitudes) between rapid and slow knee-extensions could have been attained, if patients had been able to perform knee-extensions more rapidly than observed. Hence, the accomplished maximal knee-extension velocity of 51.4 degrees/sec in this study may partly explain why the increase of 8.5% as observed in vastus lateralis did not reach the predetermined 15% (as well as may explain the non-significant observations for vastus medialis).

Muscle activity in vastus medialis: The findings in the present study are indistinct as an uneven increase in quadriceps muscle activity was observed between vastus medialis and vastus lateralis. Some explanations can be offered as to why the observations for vastus medialis where non-significant. An open kinetic chain knee-extension exercise was used in the present study to assess and compare the quadriceps muscle activity during slow and rapid knee-extension velocities, respectively. This particular knee-extension exercise was chosen for this study, since it is an isolated knee-extensor exercise that, in healthy individuals, induces a high degree of neural efferent drive to the quadriceps muscle in general, without eliciting higher levels of synergistic or antagonistic muscle activity around the knee.[39] Specific activation of the quadriceps muscle is highly relevant, due to the persistent weakness and inhibition especially affecting the quadriceps muscle following TKA. Furthermore, the open chain knee-extension exercise is a single-joint, non-weight bearing exercise, in which the exercise machine stabilizes the body throughout the movement. Consequently, the motor-task was performed without high demands to functional ability and balance, which was viewed as essential, as patients should focus on rapid velocity only. However, other studies in healthy adults have shown that open chain knee-extensions may induce a higher degree of activation of vastus lateralis compared to vastus medialis.[43,44] These observations could, at least in part, offer some explanation as to why the vastus medialis was not activated to the same degree during the rapid contractions.

Another possible explanation to the observed uneven increase in muscular activity of the explored vastii muscles, between slow and rapid knee-extensions is intra-articular knee swelling which is a common knee related symptom following TKA.[11] Experimentally induced knee-swelling is known to inhibit the quadriceps muscle [45,46] and some studies have found the vastus medialis to be inhibited earlier and by lesser amounts of fluid than the vastus lateralis.[47,48] Accordingly, although there is no clear consensus in the literature on this topic, the potential presence of knee joint fluid, may have contributed to the uneven increase in muscle activity between vastus medialis and vastus lateralis, during rapid knee-extensions. That is, because the vastus medialis may have been inhibited more, the greater voluntary drive associated with the rapid contractions was of a magnitude that elicited an increase in vastus lateralis activation only, or to a greater extent. However, the potential presence of knee joint fluid was not measured.

Clinical implications: Arthrogenic muscle inhibition[17] is a major barrier for the success of rehabilitation of patients with TKA.[2,7] Especially the quadriceps muscle is subject to a significant loss of function,[12] which is associated with decreased maximal knee-extension strength, quadriceps activation and functional capacity in patients 12 months post TKA.[13,49] The recent study by Doerfler et al suggested some positive preliminary effects of high velocity exercise compared to slow velocity exercise in terms of improved walking distance and knee-extensor muscle strength in patients with TKA after surgery, supporting the use of high velocity exercise.[30]

In many daily activities, where a fast reaction is required, e.g. during prevention of a fall, the ability to contract rapidly (rate of force development [RFD]) is of great importance.[50] The RFD seems to be lower in patients with TKA compared to pre-operative values [51] and age-matched healthy controls.[52] Pertaining to the notions above, explosive resistance training would be a rational option, as this type of resistance training has shown to increase RFD in healthy elderly [27] and in patients with total hip replacement,[29] and elicits greater improvement on RFD results and better effect on functional outcome than conventional resistance training in healthy age-matched peers.[53]

The clinical implication of the above is that intervention and rehabilitation strategies, when seeking to increase central activation and reduce AMI, may benefit from modalities that facilitate RFD, as in the present study. Therefore, it seems plausible that explosive type contractions, as performed in this study, are highly relevant to employ in this group of patients to target the RFD deficit and thereby improve functional capability. But as this study investigated short-term effects only, any long-term effects of high velocity resistance training on RFD need to be investigated further. It also needs to be investigated further whether moving the load more medially during the knee extensions could facilitate greater activation of the vastus medialis.

LIMITATIONS

The present randomized cross-over study investigated the short term effects only, i.e. the instantaneous effect of knee-extension velocity on muscle activity. Thus it is not possible to draw conclusions on long term effect of this training modality on knee-extension velocity and muscle activity in either of the investigated muscles. Likewise, the authors do not know if possible physiological gains from knee-extension exercise translate into improved functional performance. Further, the long term effects on pain levels after the test session are unknown.

CONCLUSIONS

Four to eight weeks after their TKA, the patients in the present study were able to conduct rapid knee-extensions according to the experimental protocol with an approximately doubled angular velocity compared to slow knee-extensions. Rapid knee-extensions increased the vastus lateralis muscle activity more than slow knee-extensions, but the same response was not seen in the vastus medialis. It is not known if this increase in vastus lateralis activity is sufficient to reduce AMI. Knee pain during knee-extensions was not different between slow and rapid knee-extensions while knee pain following the rapid knee-extensions was slightly higher than following the slow knee-extensions. The patients' ability to voluntarily perform knee-extension more rapidly and thereby achieve higher degrees of angular velocities than observed in this study may not be accomplished without specific training of rapid, explosive type knee-extensions for a longer period of time. Thus, whether the significant, albeit relatively small, difference in vastus lateralis muscle activity has a clinical relevant impact needs to be investigated further.

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